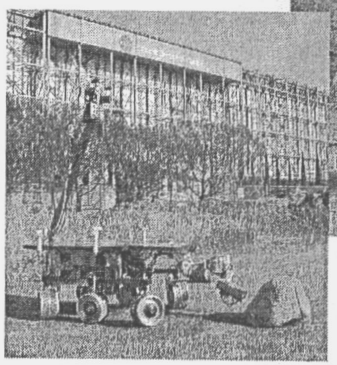
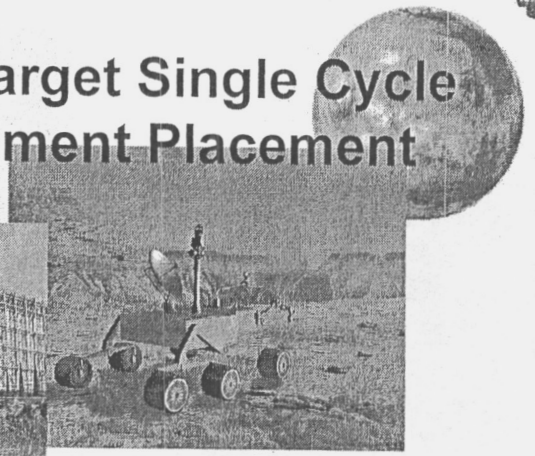
Multi-Target Single Cycle Instrument Placement



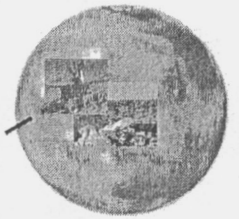


Maria Bualat (presenter), Liam Pedersen, David E. Smith, Matthew Deans, Randy Sargent, Clay Kunz, David Lees, Srikanth Rajagopalan

Robotic Exploration of Mars

Sojourner

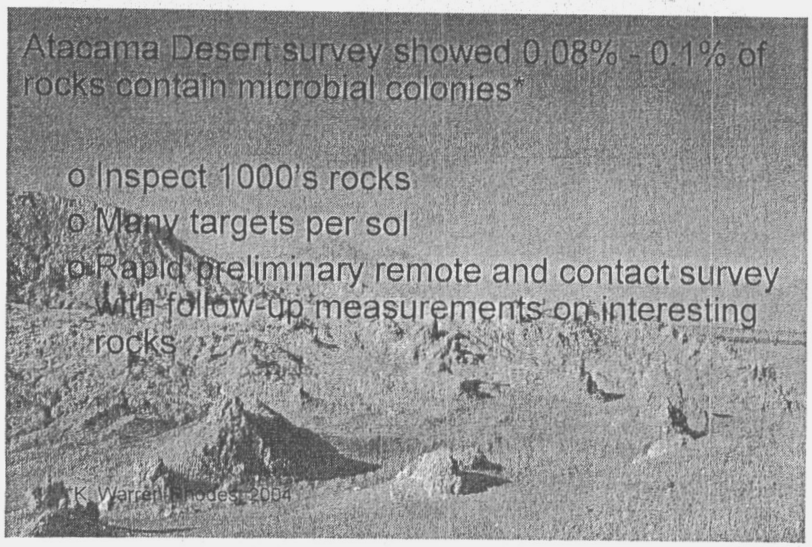
- Max distance from Lander: 12 M
- Total distance traversed 100M
- Time spent waiting: 40-75%
- 2.4 uplinks per science target
- Science cut in half during extended mission



MER

- 3-4 sols for instrument placement on a science target
- 10 sols at each interesting rock
- 240 co-located ground support scientists and engineers for 24/7 operations (primary mission)

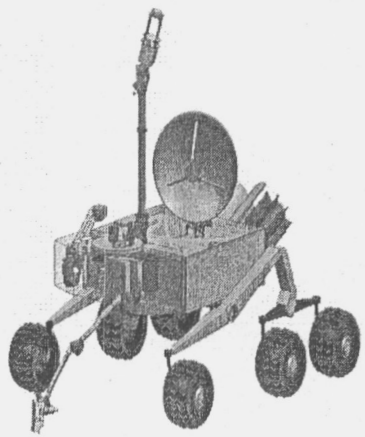
Robotic Site Survey



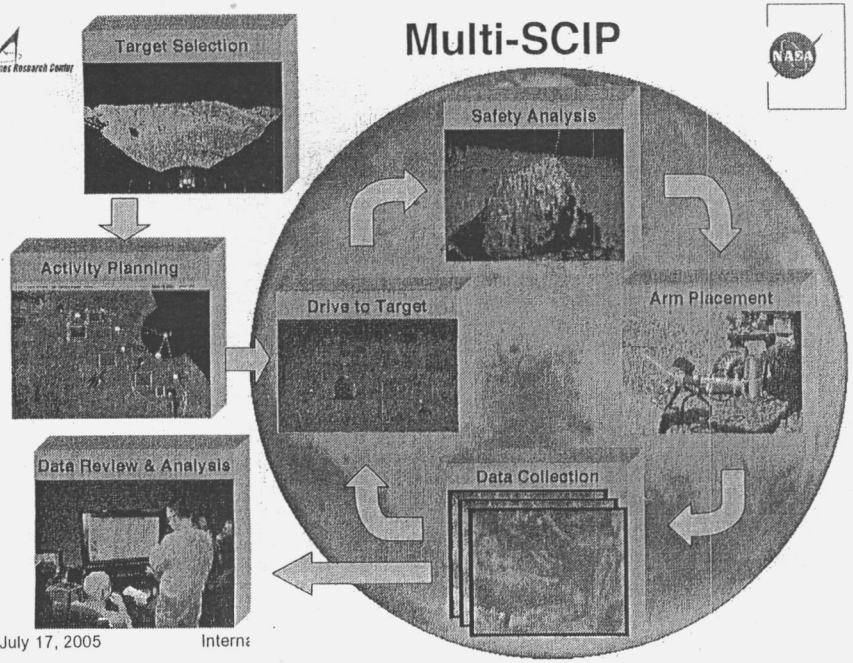
Multi-SCIP Research Goals

Multi-Target Single Cycle Instrument Placement (Multi-SCIP):

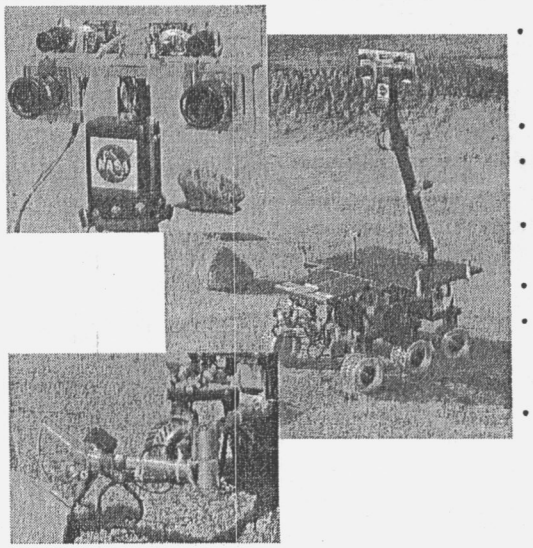
- 10m approach
- 1 cm accuracy
- Multiple targets / command cycle
- Safe operations
  - Safe instrument placements
  - Respect flight rules (e.g., power and time constraints)



Multi-SCIP



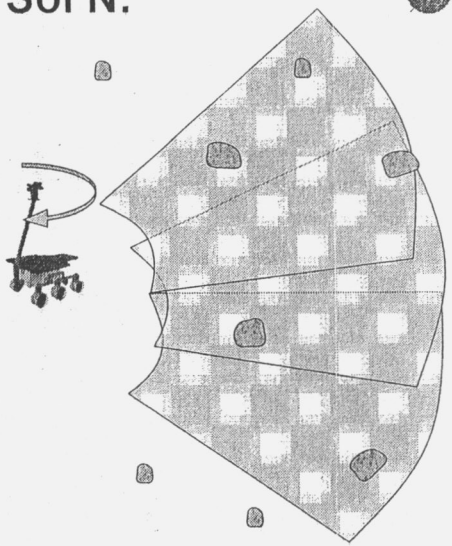
K9 Rover

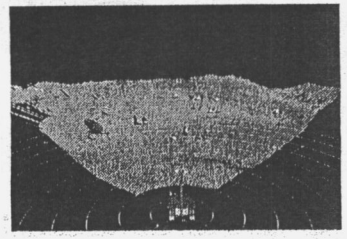


- 6 wheel steer rocker-bogey chassis (FIDO, MER)
- 70% MER size
- 1.2 GHz Pentium M laptop running Linux OS
- Odometry and compass/inclinometer
- CLARAty architecture
- 5 DOF manipulator w/ CHAMP microscopic camera
- SciCams, NavCams and HazCams

By Sol N:

- Rover at site
- Image Panorama
- Downlink data
- Data products available for review
- Stereo Model of Environment

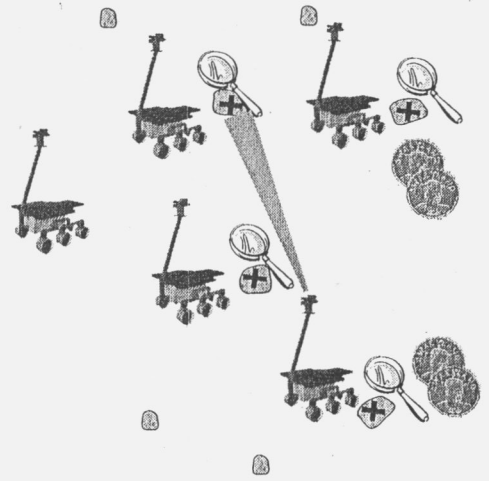


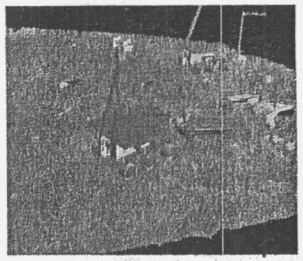


Viz

Observation Requests

- Target point
- Instruments
  - CHAMP microcsope
  - Science Cameras
  - [parameters]
- Constraints
  - Time of day
  - Must target be tracked?
- Observation point
  - pose rover must be at to acquire observation (depends on instrument)
- Value of Targets (Utility)



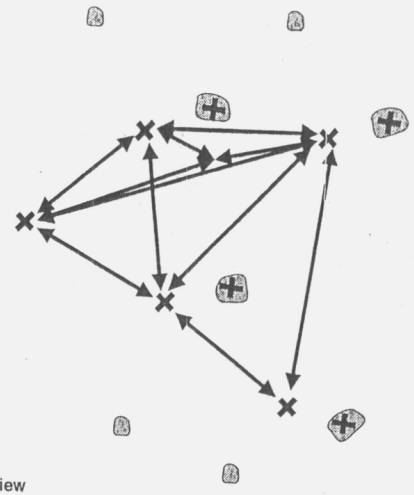


Viz

Path Generation

- Straight line paths between all pairs of points
- Users indicate obstacle regions as required
- Consolidation of similar paths
- Prune paths most likely to result in tracking failures

PlanView (PathGen)

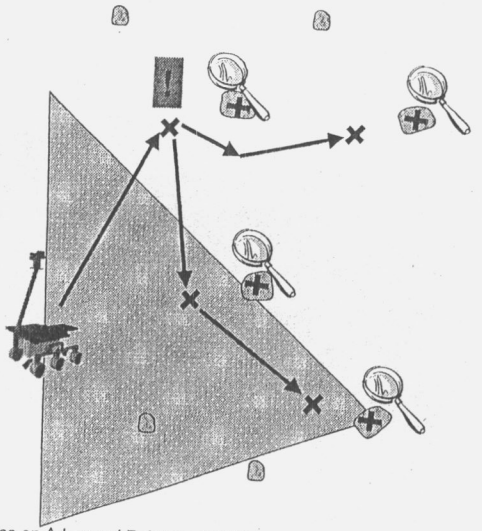


Off-Board Contingency Planning

Uncertainty everywhere!

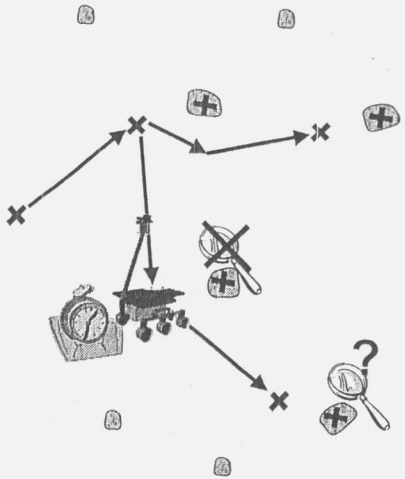
Multiple Targets:

- Over-subscription problem – more targets than resources
  - Solve "orienteering problem" for goal selection
- Increased chance of losing targets as tracking "constraints" violated.
  - Contingency plans from points where failure is detected.



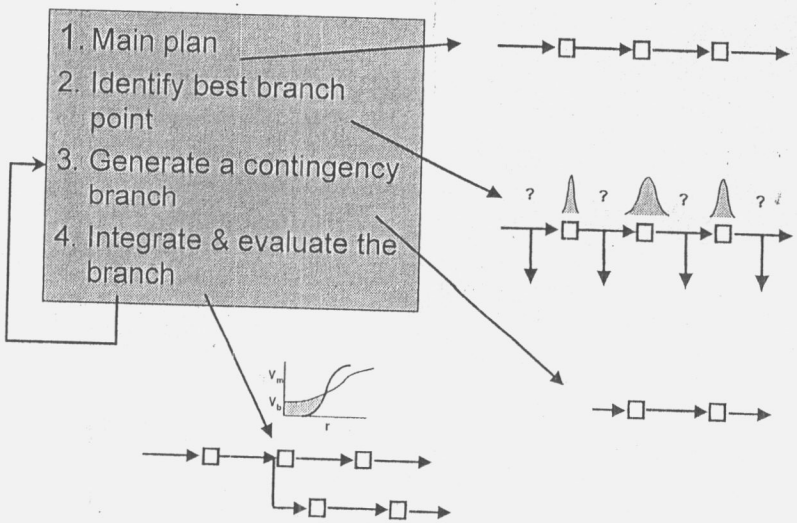
Contingencies on Resources

- Flight rules impose strict time and energy constraints
- Significant uncertainty in time and energy
- Contingency branches based on resource availability
  - Need to detect impending resource scarcity with sufficient lead time to do something about it



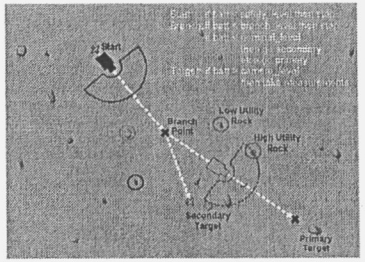
Contingency Planning Approach

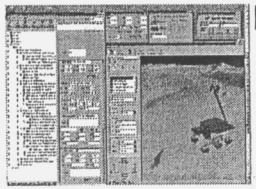
1. Main plan
2. Identify best branch point
3. Generate a contingency branch
4. Integrate & evaluate the branch

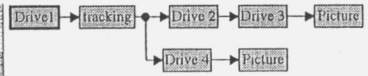


Plan Review and Sequence Generation

- Generate sequence
  - Concurrent Contingent Rover Language (C-CRL)
- Execute sequence in simulation
- Iterate planning process until satisfied
- Uplink to rover



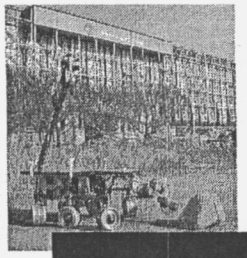


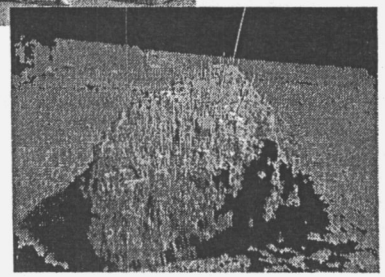


Mission Simulation Facitily
CRL Executive

Sequence Execution

- Track targets and navigate to them
- At each target in sequence do:
  - Safety check
  - Safe placement on target
  - Acquire science data
- Monitor resources (time, energy) and tracking status
  - Do alternate plans if off nominal
- Uplink science data back to Mission Control

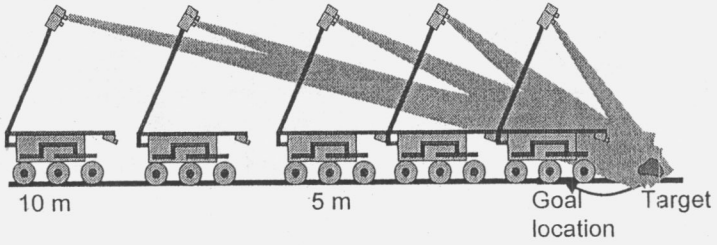




Visual Target Tracking

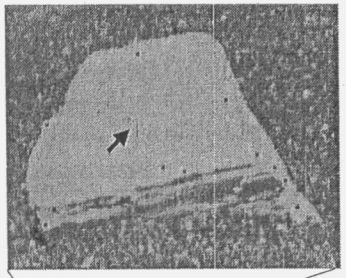
Multiple targets, 10m distant targets, 1cm precision

- Long (> 20m) traverses
  - Large deduced reckoning error (~10% distance traveled)
  - 2-3 hrs tracking duration
- Large target appearance changes

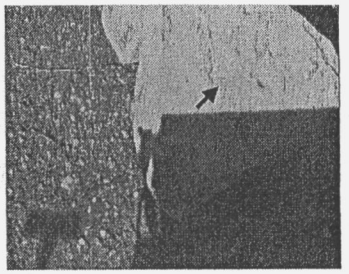


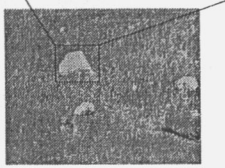
Featureless Targets, Scale Changes & Shadows

View from 10m away



View from 1m away



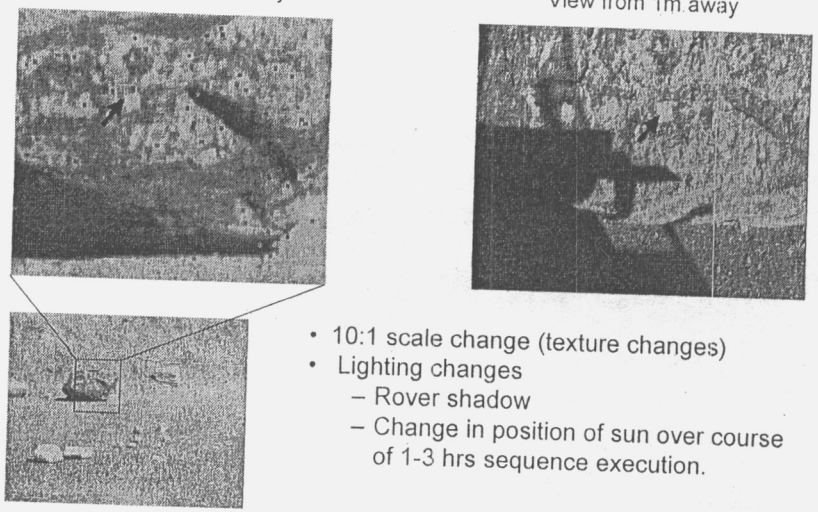


- Target point selected by scientists may not correspond to any visually distinctive features
- Note appearance of texture and rover shadow in close up image
- Note: 10m traverse → 10:1 scale change

Lighting Changes

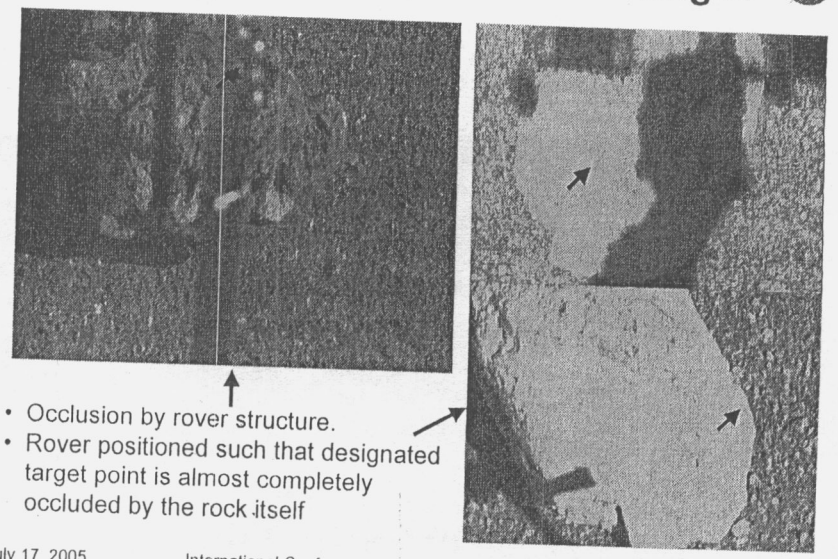
View from 10m away

View from 1m away



- 10:1 scale change (texture changes)
- Lighting changes
  - Rover shadow
  - Change in position of sun over course of 1-3 hrs sequence execution.

Occlusions & Orientation Changes



- Occlusion by rover structure.
- Rover positioned such that designated target point is almost completely occluded by the rock itself

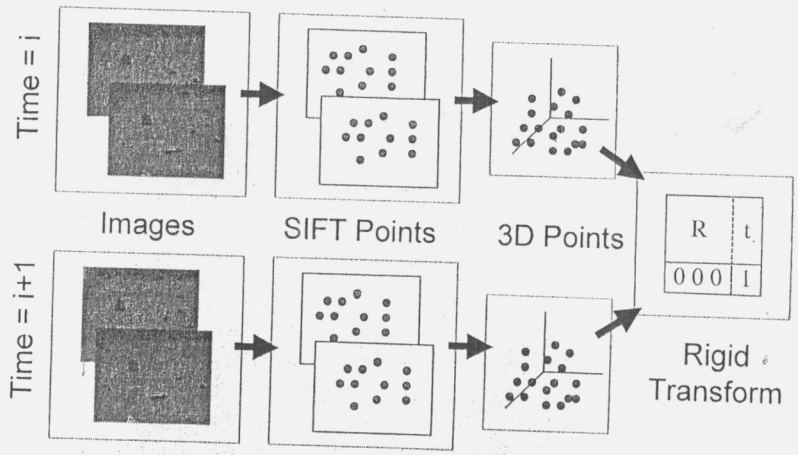
Approach: 2D Interest Points

SIFT interest operator/descriptor

Fast global matching, no "search"

[Lowe, D. G., "Distinctive image features from scale-invariant keypoints," *International Journal of Computer Vision,* submitted June 2003.]

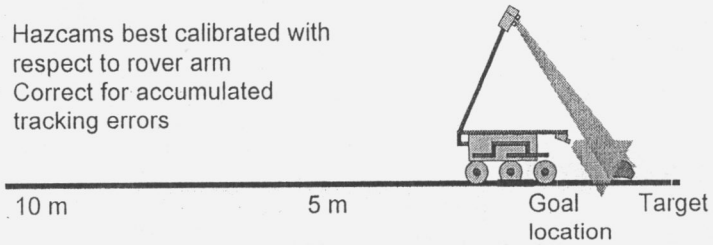
3D SIFT Target Tracker



- Integrate motion estimates for each target throughout traverse
- Small increasing tracking error during traverse

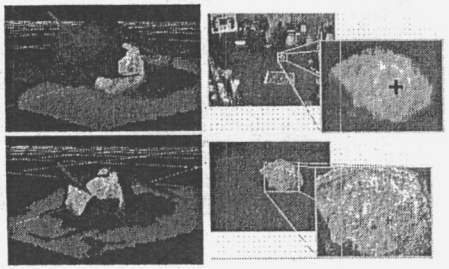
Camera Hand-off

- Hazcams best calibrated with respect to rover arm
- Correct for accumulated tracking errors

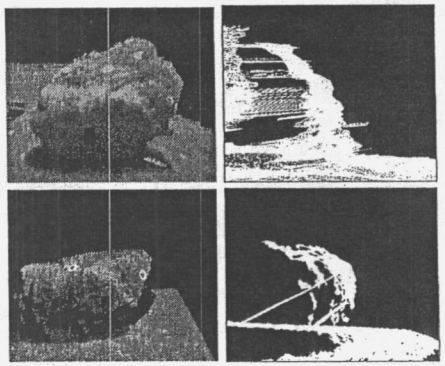


Mesh Registration for Scicam to Hazcam Hand-Off

- Match originally acquired 3D model of target with Hazcam 3D model



Safe Placement

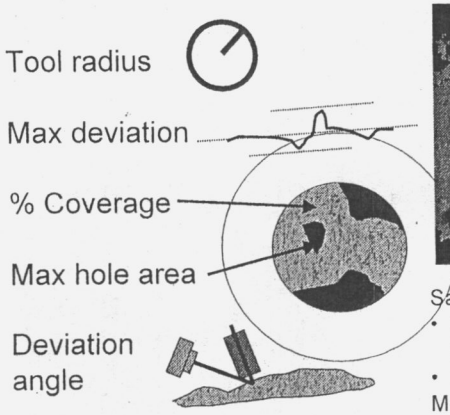


Science Cameras (11 m)

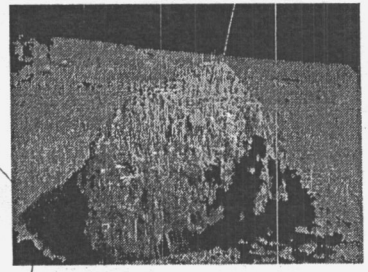
Hazard Cameras (1 m)

- Cannot guarantee target point chosen from 10m won't damage instrument.
- Potentially large tracking/hand-off error
- Close evaluation of target to confirm presumed target point is safe, and find close alternate if not.

Instrument Placement Safety Evaluation



Uses several geometric criteria to ensure safety of instrument Placement location



Safety Check

- Confirm target area will not damage instrument
- Find nearest safe locations

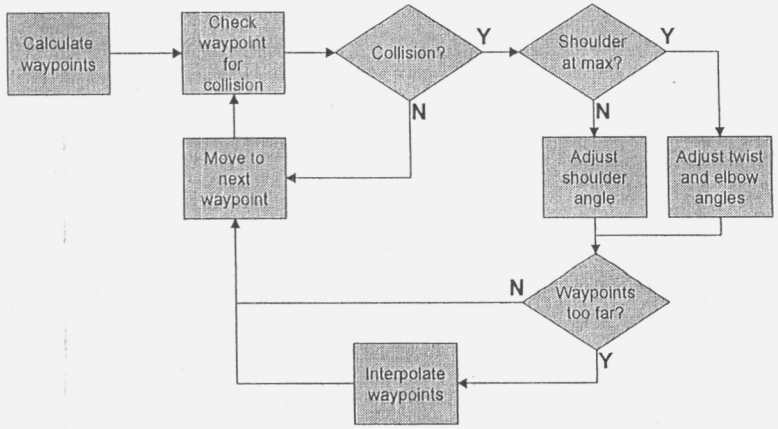
Motion Planning

- Confirm reachable and collision free path

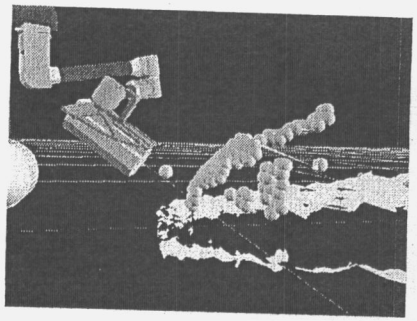
Placement

- Confirm with contact sensors
- **Take measurement**

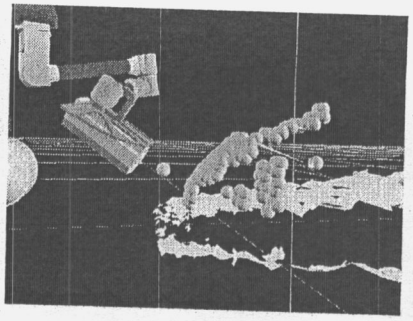
Arm motion planning



Arm motion planning



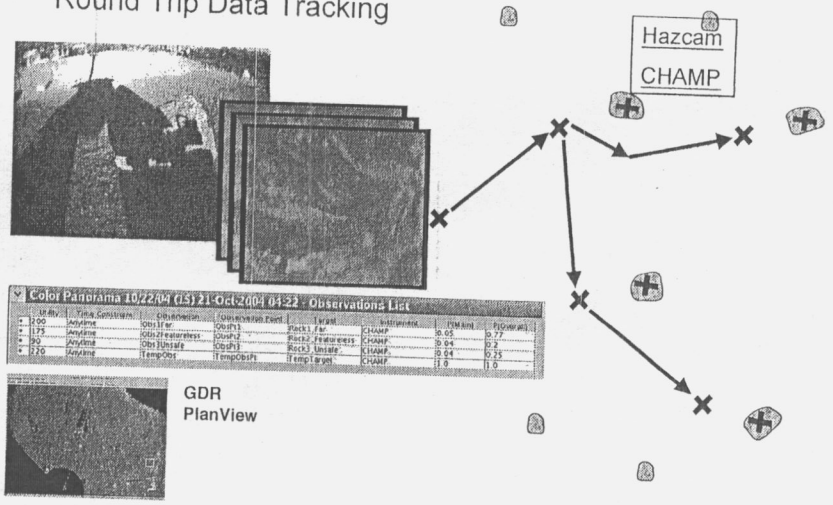
Original waypoints



Safe arm motion

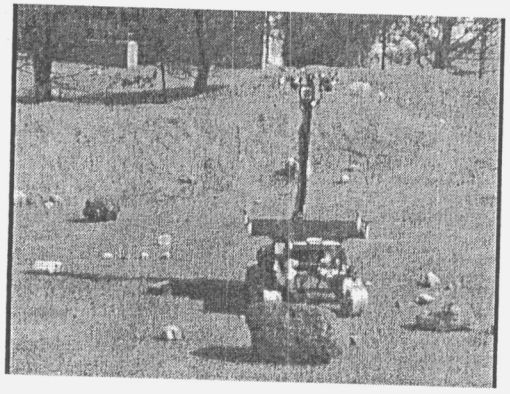
Data Products & Execution Review

Round Trip Data Tracking



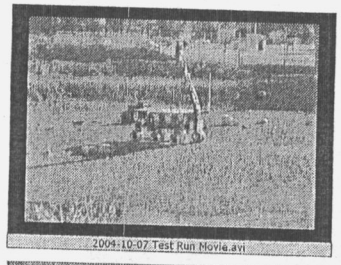
GDR
PlanView

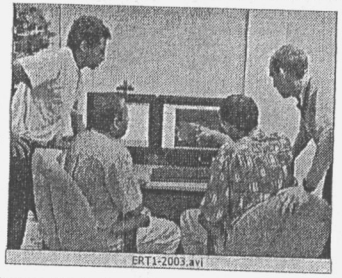
2004 Multi-SCIP Demonstration



Accomplishments

- 2004: Multi-Target Single Cycle Instrument Placement
  - 4 targets (1:23 hrs execution)
  - Targets ~ 10m distant
  - Traverse > 10m
  - Up to 1cm accuracy
  - Anticipated fault recovery and resource monitoring
  - Round trip data tracking
- 2003: Single Cycle Instrument Placement
  - Target ~3m distant
  - ~5cm precision
  - Automatic hand-off
  - Opportunistic science
  - ground based contingency planning.
  - Satellite uplink/downlink to rover in Quarry
- 2002: Automated instrument placement on rock





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- NASA ARC Code T/TI
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  - Collaborative Assistant Systems
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